POLISHING PAD REFURBISHER FOR IN SITU, REAL-TIME CONDITIONING AND CLEANING OF A POLISHING PAD USED IN CHEMICAL-MECHANICAL POLISHING OF MICROELECTRONIC SUBSTRATES

TECHNICAL FIELD

The present invention relates to an apparatus for selectively cleaning and conditioning the surface of a polishing pad used in chemical-mechanical polishing of semiconductor wafers and other microelectronic substrates.

BACKGROUND OF THE INVENTION

Chemical-mechanical polishing ("CMP") processes remove material from the surface of a wafer in the production of ultra-high density integrated circuits. In a typical CMP process, a wafer is pressed against a polishing pad in the presence of a slurry under controlled chemical, pressure, velocity, and temperature conditions. The slurry solution generally contains small, abrasive particles that abrade the surface of the wafer, and chemicals that etch and/or oxidize the surface of the wafer. The polishing pad is generally a planar pad made from a relatively soft, porous material such as blown polyurethane. Thus, when the pad and/or the wafer moves with respect to the other, material is removed from the surface of the wafer by the abrasive particles (mechanical removal) and by the chemicals in the slurry (chemical removal).

FIG. 1 schematically illustrates a conventional CMP machine **10** with a platen **20**, a wafer carrier **30**, a polishing pad **40**, and a slurry **44** on the polishing pad. An under-pad **25** is typically attached to the upper surface **22** of platen **20**, and the polishing pad **40** is positioned on the under-pad **25**. A drive assembly **26** rotates the platen **20** as indicated by arrow A, or in another existing CMP machine the drive assembly **26** reciprocates the platen **20** back and forth as indicated by arrow B. The motion of the platen **20** is imparted to the pad **40** through the under-pad **25** because the polishing pad **40** frictionally engages the under-pad **25**. The wafer carrier **30** has a lower surface **32** to which a wafer **12** may be attached, or the wafer **12** may be attached to a resilient pad **34** positioned between the wafer **12** and the lower surface **32**. The wafer carrier **30** may be a weighted, free-floating wafer carrier, or an actuator assembly **36** may be attached to the wafer carrier **30** to impart axial and rotational motion, as indicated by arrows C and D, respectively.

In the operation of the conventional planarizer **10**, the wafer **12** is positioned face-downward against the polishing pad **40**, and then the platen **20** and the wafer carrier **30** move relative to one another. As the face of the wafer **12** moves across the planarizing surface **42** of the polishing pad **40**, the polishing pad **40** and the slurry **44** remove material from the wafer **12**.

In the competitive semiconductor industry, it is desirable to maximize the throughput of the finished wafers and minimize the number of defective or impaired devices on each wafer. The throughput of CMP processes is a function of several factors, one of which is the rate at which the thickness of the wafer decreases as it is being planarized (the "polishing rate"). Because the polishing period per wafer decreases with increasing polishing rates, it is desirable to maximize the polishing rate within controlled limits to increase the number of finished wafers that are produced in a given period of time.

One problem with CMP processing is that the throughput may drop because the condition of the polishing surface on the pad deteriorates while polishing a wafer. The deterioration of the polishing pad surface is caused by waste particles from the wafer, pad, and slurry that accumulate on the polishing surface of the polishing pad. Since the accumulations of waste particles alter the condition of the polishing surface on the polishing pad, the polishing rate tends to drift over time. For example, after polishing a single wafer for only 4 minutes with a Rodel IC-1000 polishing pad and a Rodel ILD-1300 slurry (both of which are manufactured by Rodel Corp. of Arizona), the polishing rate drops and reduces the throughput for semiconductor wafers. Many semiconductor manufacturers accordingly recondition the pad after each wafer, but unless the reconditioning process is performed in situ and in real-time, then the reconditioning of the pad also causes down-time that reduces throughput. Thus, the waste particles on the polishing surface reduce the throughput of the CMP process.

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CMP processes must also consistently and accurately produce a uniform, planar surface on the wafer because it is important to accurately focus the image of circuit patterns on the surface of the wafer. As the density of integrated circuits increases, it is often necessary to accurately focus the critical dimensions of the circuit pattern to better than a tolerance of approximately 0.1 μm. Focusing the circuit patterns to such small tolerances, however, is very difficult when the distance between the emission source and the surface of the wafer varies because the surface of the wafer is not uniformly planar. In fact, several devices may be defective on a wafer with a non-uniformnly planar surface. Thus, CMP processes must create a highly uniform, planar surface.

Another problem with CMP processing is that the accumulations of waste particles reduce the uniformity of the polished surface because they do not accumulate uniformly across the polishing surface of the pad. The polishing rate accordingly varies from one region on the pad to another resulting in a nonuniform polished surface on the wafer. Therefore, in light of the problems associated with accumulations of waste particles on polishing pads, it is necessary to periodically clean and condition the polishing surface to remove such accumulations and bring the polishing pad back to a desired condition.

Polishing surfaces on polishing pads are typically cleaned by brushing the pad with a brush, or by flushing the pad with a fluid. To perform the brushing and flushing processes, the wafer is generally removed from the pad while the brush or fluid engages the polishing surface of the polishing pad. One problem with the brushing and flushing processes, therefore, is that a significant amount of down-time is necessary to merely clean the polishing pad. Thus, it would be desirable to develop a pad cleaner that effectively cleans the pad in situ and in real-time.

Polishing surfaces of polishing pads are typically conditioned with a diamond embedded plate mounted to a separate device that moves the plate across the polishing pad to abrade the surface of the pad. Some pad conditioners remove a portion of the upper layer of the deteriorated polishing surface to form a new, clean polishing surface. One problem with conventional pad conditioners is that they condition the pad substantially uniformly across the polishing surface. Since the wafers only polish on a well-defined area of the pad (usually a concentric band spaced radially away from both the center of the pad and the perimeter of the pad), the pad conditioning needs to be performed proportionate to the pad surface wear. Moreover, it is desirable to condition a pad in situ and in real-time to avoid costly down-time associated with conditioning processes that stop the polishing of the wafer. Thus, it would be desirable to develop a device for

selectively conditioning areas on the pad that require conditioning in situ and in real-time.

SUMMARY OF THE INVENTION

The inventive pad refurbisher provides in situ, real-time conditioning and/or cleaning of a polishing surface on a polishing pad used in chemical-mechanical polishing of a semiconductor wafer. The pad refurbisher has a body adapted for attachment to a wafer carrier of a chemical-mechanical polishing machine, and a refurbishing element connected to the body. The body has a face positioned proximate to a perimeter portion of the wafer carrier and facing generally toward the polishing surface of the polishing pad. The body travels with the wafer carrier as the wafer carrier moves over the polishing pad. The refurbishing element is connected to the face of the body so that the refurbishing element can operatively engage the polishing surface substantially adjacent to the perimeter of the wafer carrier. The refurbishing element is a pad conditioning device and/or a pad cleaning device that conditions and/or cleans the polishing surface of the pad to remove waste particles from the polishing surface of the polishing pad and place the pad in a desired polishing condition. In operation, the refurbishing element travels with the wafer carrier and is selectively engaged with the polishing surface while the wafer carrier presses the wafer against the polishing surface to selectively condition and/or clean generally only the deteriorated areas on the pad.

In one embodiment, the face of the body is a distal face defining a ring positioned radially outwardly from the perimeter of the wafer carrier, and the refurbishing element is either a diamond embedded pad conditioner or a brush-like pad cleaner. In another embodiment, the body has a first ring with a first refurbishing element and a second ring with a second refurbishing element. The first ring is positioned radially outwardly from the perimeter of the wafer carrier, and the second ring is positioned radially outwardly from the first ring. The first refurbishing element is preferably a brush-like pad cleaner and the second refurbishing element is preferably a diamond embedded pad conditioner.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross-sectional view of a chemical-mechanical polishing machine in accordance with the prior art.

FIG. 2 is a schematic cross-sectional view of a pad refurbisher in accordance with the invention.

FIG. 3 is a bottom plan view of an embodiment of the pad refurbisher of FIG. 2.

FIG. 4 is a bottom plan view of another embodiment of the pad refurbisher of FIG. 2.

FIG. 5 is a schematic cross-sectional view of another pad refurbisher in accordance with the invention.

FIG. 6 is a bottom plan view of the pad refurbisher of FIG. 5.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a CMP polishing pad refurbisher that selectively conditions and cleans generally only the deteriorated regions of a polishing surface on a polishing pad in situ and in real-time while a microelectronic substrate (e.g., a semiconductor wafer) is polished. An important aspect of the invention is that the pad refurbisher travels with the wafer carrier and positions a refurbishing element proximate to the wafer carrier without limiting the travel of the wafer carrier or over-conditioning unused regions on the polishing surface of the polishing pad. Another important aspect of the invention is that the refurbishing element may have a pad conditioner and a pad cleaner to simultaneously condition and clean the polishing surface in situ and in real-time while a wafer is polished. The pad refurbisher of the invention accordingly provides a clean and properly conditioned polishing surface on the polishing pad that enhances the uniformity of the finished surface on the wafer and the throughput of the CMP process. FIGS. 2–6, in which like reference numbers refer to like parts throughout the various views, illustrate pad refurbishers in accordance with the invention.

FIG. 2 illustrates a pad refurbisher **50** in accordance with the invention. The pad refurbisher **50** has a body **60** attached to a wafer carrier **30** of a polishing machine, such as the polishing machine **10** shown in FIG. **1**. The body **60** has a distal face **62** positioned proximate to the perimeter of the wafer carrier **30** and facing toward the polishing surface **42** of the polishing pad **40**. A refurbishing element **70** is attached to the distal face **62**. The refurbishing element **70** is preferably a pad conditioner or a pad cleaner. In the case of a pad conditioner, the refurbishing element **70** is preferably a separate pad with a plurality of embedded diamonds, or in other embodiments the diamonds may be embedded directly into the distal face **62**. In the case of a pad cleaner, the refurbishing element **70** may be a brush or a number of fluid jets attached to the distal face **62** of the body **60**. Both the pad conditioner and the pad cleaner are directed towards the polishing surface **42** of the polishing pad **40** to be selectively engaged with the polishing surface **42**, as discussed in detail below.

The body **60** may be fixed to the wafer carrier **30**, or as shown in FIG. **2**, the body **60** may be slidably attached to the wafer carrier **30** to move along a vertical axis substantially normal to the polishing surface **42** of a polishing pad **40** (shown by axis Z—Z). A vertical slot **64** extends along an inner wall of the body **60** facing the wafer carrier **30** to slidably receive a key **66** protruding from the perimeter of the wafer carrier **30**. As the wafer carrier **30** rotates, the key **66** engages the side wall of the slot **64** to impart the rotational movement of the wafer carrier **30** to the body **60**. The key **66** also slides within the slot **64** as the body **60** moves vertically along the Z—Z axis with respect to the wafer carrier **30** to allow the distal face **62** of the body **60** to be selectively positioned proximate to the polishing surface **42**.

In a preferred embodiment, the body **60** is moved along the vertical axis Z—Z with respect to the wafer carrier **30** by a number of linear displacement actuators **80** positioned between a support member **63** attached to the body **60** and the top surface of the wafer carrier **30**. The actuators **80** may be pneumatic cylinders, hydraulic cylinders, servomotors, springs, or any other suitable device that provides linear displacement between objects. The support member **63** may be a beam or plate connected to the body **60** (as shown in FIG. **2**), or the support member may be made integrally with the body **60**. A hole **65** through the support member **63** is positioned to slidably receive the shaft/actuator **36** of the wafer carrier **30** and allow the support member **63** to move along the vertical axis Z—Z with respect to the actuator **36**. The actuators **80** preferably have a housing **82** attached to the wafer carrier **30** and an extensible rod **84** attached to the support member **63**. As the rods **84** push against or pull on the support member **63**, the body **60** moves upward or downward, respectively, along the vertical axis Z—Z with

respect to the wafer carrier **30** to adjust the position of the distal face **62** with respect to the pad **40**.

In other embodiments, the actuators **80** may act directly against the body **60** instead of the support member **63**. For example, the actuator may be a motor (not shown) that rotates a drive gear (not shown) against a rack of teeth (not shown). The motor is connected to one of the wafer carrier **30** or the body **60**, and the rack of teeth is positioned on the other of the wafer carrier **30** or the body **60**. As the motor rotates the drive gear against the teeth, the drive gear moves the body **60** vertically with respect to the wafer carrier **30**. Importantly, the actuator acts against the wafer carrier **30** and either the body **60** or a support member **63** connected to the body **60** to selectively move the body **60** vertically with respect to the wafer carrier **30** along the vertical axis Z—Z.

The actuators may be controlled manually or by a processor to selectively engage the refurbishing element **70** with the polishing surface **42** of the pad **40**. In general, the refurbishing element **70** is selectively engaged with the polishing pad **40** on the areas of the planarizing surface **42** that contact the wafer **12**. Since the wafer **12** usually contacts the pad **40** in a concentric band at a medial radial distance from the center of the pad **40**, the actuators **80** are preferably controlled to lower the refurbishing element against the polishing surface **42** in the area defined by the concentric band. The actuators **80** may also control the pressure between the refurbishing element **70** and the pad **40** to provide a substantially constant pressure therebetween that does not affect the pressure between the wafer **12** and the pad **40**. In one embodiment, the actuators **80** are manually set to position the body **60** so that the refurbishing element **70** engages the polishing surface **42** when the wafer carrier **30** presses the wafer **12** against the pad **40**. To manually set the actuators, the wafer **12** is placed against a reference surface and then the refurbishing element **70** is lowered against the reference surface. The reference surface can be either the polishing pad **40** or another platform (not shown). In another embodiment, the actuators **80** are springs that bias the refurbishing element **70** against the polishing surface **42** to provide a substantially constant pressure between the refurbishing element **70** and the polishing pad **40**. When the actuators are springs, the refurbishing element **70** is preferably positioned slightly below the face of the wafer **12** when the wafer **12** is off of the pad **40** so that the refurbishing element **70** engages the polishing surface **42** as the wafer carrier **30** presses the wafer **12** against the polishing pad **40**.

In operation, the wafer carrier **30** is lowered to engage the wafer **12** with the polishing surface **42** of the polishing pad **40**. As discussed above with respect to FIG. **1**, the platen **20** and polishing pad **40** rotate in a direction R_p while the wafer carrier **30** rotates the wafer **12** in a direction R_w. The wafer carrier **30** also translates the wafer **12** in the direction T across the polishing surface **42** of the polishing pad **40**. As the wafer **12** is polished on the polishing surface **42**, the actuators **80** position the body **60** with respect to the wafer carrier **30** to selectively engage the refurbishing element **70** with the polishing surface **42**. The polishing surface **42** surrounding the wafer **12** is accordingly conditioned (when the refurbishing element is a pad conditioner) or cleaned (when the refurbishing element **70** is a cleaning element) while the wafer **12** is polished. The actuators **80** selectively disengage the refurbishing element **70** from the polishing surface **42** by extending the rods **84** against the support structure **63** to move the body **60** upwardly along the vertical axis Z—Z. The refurbishing element **70** is selectively removed from the polishing surface **42** over areas of the polishing pad **40** that do not need to be conditioned or cleaned. Thus, by selectively engaging and disengaging the refurbishing element **70** with the polishing surface **42**, the pad refurbisher **50** can selectively condition or clean only the deteriorated areas on the polishing surface **42** that need to be brought back to an acceptable polishing condition.

The body **60** and the distal face **62** of the body **60** are shaped to position the refurbishing element **70** proximate to the perimeter of the wafer carrier **30** about at least a portion of the perimeter of the wafer carrier **30**. For example, the body **60** may be attached to only a single side of the wafer carrier **30**, and the body **60** may be shaped so that the distal face **62** and refurbishing element **70** are positioned asymmetrically about a fraction of the perimeter of the wafer carrier **30**. In some instances, however, an asymmetrical mounting of the body **60** may impart asymmetrical forces on the wafer carrier **30**. In particular, as the wafer carrier **30** rotates an asymmetrically positioned distal face **62** and refurbishing element **70** across the polishing pad **40**, the centrifugal force of the refurbishing element **70** may cause the wafer carrier **30** to wobble. Also, since the polishing pad **40** will exert a force on the refurbishing element **70**, an asymmetrically positioned refurbishing element **70** will cause the force between the wafer **12** and the polishing pad **40** to be uneven across the surface of the wafer **12**. Accordingly, the body **60** is preferably shaped and attached to the wafer carrier **30** to symmetrically position the distal face **62** and refurbishing element **70** with respect to the center of the wafer carrier **30**, thus reducing or eliminating any uneven forces on the wafer caused by an asymmetrical design.

FIGS. **3** and **4** illustrate two embodiments of the pad refurbisher **50** in which the body **60**, the distal face **62**, and the refurbishing element **70** are symmetrically positioned with respect to the center of the wafer carrier **30**. It will be appreciated that the invention is not limited to the embodiments illustrated in FIGS. **3** and **4**, as other symmetrical configurations are within the scope of the invention. Referring to FIG. **3**, the body **60** is a cylindrical sleeve positioned adjacent to the perimeter of the wafer carrier **30**, and the distal face **62** is a continuous ring spaced radially apart from the perimeter of the wafer carrier **30**. The refurbishing element **70** substantially covers the complete surface area of the distal face **62**, and not just a portion as shown in FIG. **3**. Referring to FIG. **4**, the body **60** is a cylindrically shaped sleeve positioned adjacent to the perimeter of the wafer carrier with a number of arcuate segments **61** spaced radially apart from the perimeter of the wafer carrier **30**. The arcuate segments **61** are separated from one another by a substantially equal angular distance with respect to the wafer carrier **30**. The distal face **62** of the body **60** is defined by the bottom surface of each of the arcuate segments **61**, and a refurbishing element **70** is attached to the distal face **62** on each of the arcuate segments **61** to condition or clean the polishing surface **42**, as discussed above. In another embodiment, pad conditioners are attached to some of the arcuate segments **61** and pad cleaners are attached to other arcuate segments **61** so that the polishing surface **42** may be simultaneously cleaned and conditioned.

FIG. **5** illustrates another embodiment of a pad refurbisher **150** in which the body **60** has inner and outer rings **61**(*a*) and **61**(*b*), respectively positioned proximate to the perimeter of the wafer carrier **30**. A first refurbishing element **70**(*a*) is positioned on a distal face **62**(*a*) of the inner ring **61**(*a*), and a second refurbishing element **70**(*b*) is positioned on a distal surface **62**(*b*) of the outer ring **61** (*b*). The first refurbishing element **70**(*a*) is either a pad conditioner or a pad cleaner,